opinion

The M in STEM What is it really?

Lance Coad

St Michael's Collegiate, TAS, Australia
<lance.coad@collegiate.tas.edu.au>

The acronym STEM doubtless will conjure many meanings, and it will not serve my purpose to discuss or debate them all. I wish, rather, to reflect for a moment only on the function, role or place of mathematics when included as part of an integrated STEM activity, and this from the perspective of a teacher of mathematics. I will not attempt to expound upon what it is that constitutes an integrated STEM activity, save to suggest that it would be an educational activity designed to incorporate elements of some or all of science, technology, engineering and mathematics—and even the arts, in which case we would have a STEAM activity.

Among reactions to the integration of mathematics within STEM activities might be a somewhat deflationary view: "Yes, well, that is pretty much what we've been trying to do for a while now. Thanks for taking interest in our work!" Balanced against this might be expressed a more protectionist response: "Fine, yes, you want mathematics to be more integrated, but at what cost to mathematics? We still have a course to get through, you know." While I present these as more or less polarised caricatures, I do not doubt that both forms could find simultaneous harbour within a teacher. What, then, are we to make of the M in STEM? Are we for or against it? Would we embrace STEM extending to STEAM and beyond, or would we rather see STE, or even STEA, grow apace while M retains its dignity: austere and distinct? Is this unfair? Is 'distinctness,' by which is intended a kind of abstractness, a defining feature of mathematics? I will not presume to answer such questions, but I will venture the opinion that it is not sufficient for committed teachers of mathematics to permit such matters to be weighed in our absence.

At a recent workshop in the ACARA offices in Sydney, teachers of STEM gathered to reflect on implementations of integrated STEM projects within their schools. The projects discussed illustrated a range of interpretive stances and practical considerations—presented variously as constraints, advantages or weaknesses, according to each school's considered perspective. When those participants who had identified themselves as 'mathematics teachers' gathered in a meeting to reflect on the role of mathematics in STEM, the tone of conversation (which had been broadly celebratory of STEM in general gatherings) refined to a more focussed set of concerns, centred on the potential benefits and lurking dangers inherent in the promotion of STEM. In what follows I will draw on my reflections of that meeting, and on my own experiences teaching mathematics and STEM, to present a selection of questions and attitudes by way of a call to my fellow mathematics teachers not merely to engage in debates, but rather, to drive conversations and influence the formation of the STEM concept in their educational environments.

The reflections—beginning over the page—are presented as statements. We might agree or disagree with them. That is fine, but their purpose is to elicit a response: why do we adopt the views we do?

Reflection 1. There is a danger that STEM activities relegate the role of mathematics to a data presentation tool

"…and then the students made a chart!" Without wishing to denigrate the importance of presenting data—indeed, in an era of 'big data' I would contend that it is a matter for serious consideration—can it be said that a need to include mathematics in a project has been served if a graph is produced? If a graph is to be produced, fine, but then, what is the purpose? If it is to serve some analytical function, where is the analysis? Does the graph serve the analysis, or does the analysis justify the inclusion of the graph? Do simple charts represent the cheapest form of mathematical inclusion? If data are to be presented, then present data, but let us refrain from calling this mathematical without first making the case: Was the data gathered for a useful purpose? Was a design process employed to ensure that the data to be gathered would serve that purpose? Do the data sustain analysis? Does the analysis inform the purpose for which the data were gathered?

Experimental design can be subtle and analysis more so: What do we expect of our students? How aware of implicit detail do we expect our students to be? Is it acceptable to use linear regression, for example, if the students do not know the underlying method of least squares employed by a calculator? If that is acceptable, is it also acceptable to apply standard deviations without a careful background study? The examples can flow, but the more foundational question is this: on what basis do we decide how much a student should know about a procedure before we have the student employ the procedure?

Thus we arrive at a second reflection.

Reflection 2. Mathematics can be presented as an element within a STEM project without an expectation that students will be able to understand and apply all of the mathematical procedures

This is to ask whether it is sometimes reasonable to regard a mathematical inclusion in a STEM activity as an illustration of mathematics in use, rather than as an opportunity to engage mathematically. Is it good, for example, to demonstrate to middle school students that a procedure can be applied to rotate and shear the Cartesian plane when the underlying mathematical processes form a part of the senior curriculum but are unapproachable to most younger students? Does it suffice to suggest that such demonstrations point the way to future possibilities and could be motivational; or is it likely that such a demonstration would constitute a meaningless application of some esoteric process, reinforcing a suspicion that mathematics does not really make sense to any but a rare few?

I suspect that mathematics teachers are accustomed to developing procedures from first principles, or near approximates, and then migrating students toward more efficient algorithms. We seek to explain rather than merely apply. Is this an essential goal in the STEM context or an unnecessary constraint? If you lean toward the view that it is our task to explain, to develop from the ground up, as it were, a cohesive and comprehensive body of knowledge, you might reflect upon your own lived experience. How much of what we do and use do we actually understand? Do you know what algorithms are employed when a computer produces a graph? Do you understand how a video file is compressed and streamed? Can you explain how fuel is actually delivered to the pistons in your car's engine, and how it is converted to mechanical energy? Do you know precisely what we mean by the common term 'plastic'? How does your phone actually take pictures? Such questioning could continue indefinitely, of course. The point is, much of what we do and engage with has the character of a black box: we identify inputs and outputs, but inner transitions are beyond our ken. If we choose to open the box, we see inside a plethora of smaller boxes.

This is not to suggest that we should not teach what takes place inside mathematical boxes, but rather to ask whether it is necessary to avoid such boxes when they can be wisely and

judiciously employed to serve some pedagogical purpose. If we are to avoid mathematical black boxes, then it would seem that there will be much, indeed, that we are to avoid, which brings to mind another point on which to reflect: should all STEM activities include a mathematical component?

Reflection 3. Mathematics must be a component in all STEM activities

It could be said that an activity without mathematics cannot be called a STEM activity in virtue of the simplest definition, which seems reasonable, but the term STEM can also be read as a categorisation of a suite of approaches, broadly inclusive of science, technology, engineering and mathematics in which sense individual activities might or might not include all components and yet remain within the STEM family. If an activity does not afford a genuinely mathematical application then two options pertain: either impose a mathematical component, or else refrain from including a mathematical component. Each option entails a certain commitment to mathematics, but the latter option necessitates engagement with a particular thought: on what basis do we decide what mathematics to teach? When we engage with a process of writing or implementing new STEM projects we confront this question.

The questions do not cease once we settle on what mathematical components to include in an activity, for nipping at the heels of teaching is assessment.

Reflection 4. Mathematics must be assessed

When we have our students engage mathematically, is it necessary that assessment must ensue? Can we forgo assessment? Not all the time, perhaps, but sometimes? Are there occasions when it is better not to assess the outcome of a mathematical experience? What, after all, is the purpose of a putative assessment? Does the act of assessing enrich or diminish learning? The usual questions apply—who is assessment for; how is it to be done; how is it moderated?—but more germane to considerations here is the matter of disentangling an assessment of mathematical achievement from a project in which any or all of scientific, engineering and technological modes of behaving might have been employed. How do—or should—we distinguish mathematical from scientific behaviour? How do we distil mathematical achievement from the production of an artefact, from the delivery of a plan, the implementation of a process? We confront the nexus between content and practice, between learning and doing: and we must ask ourselves, which do we favour? Are there alternative approaches that better serve to communicate the strength of a student's mathematical engagement and achievement?

Reflection 5. Mathematics is best taught as a stand-alone discipline

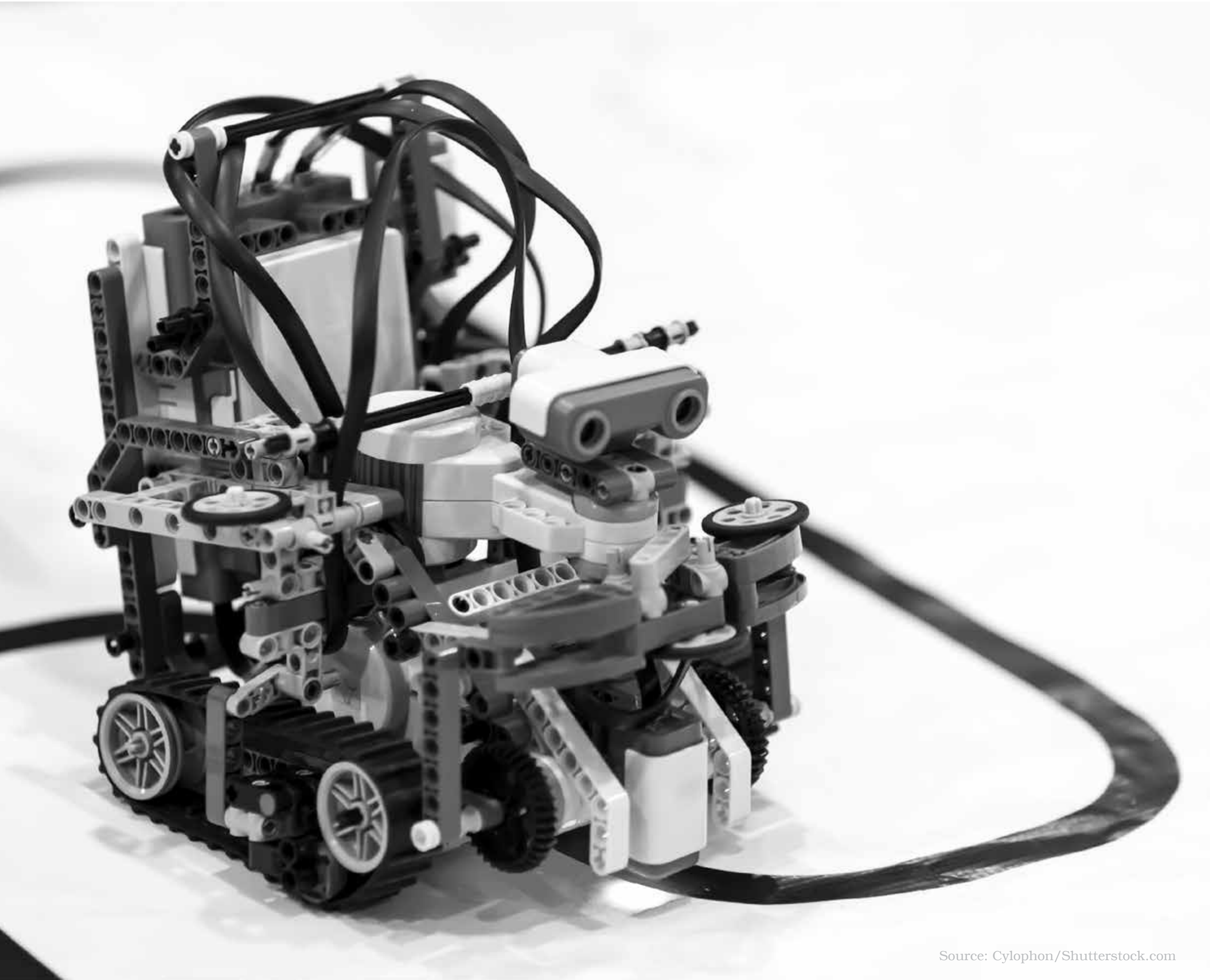
One difficulty inherent in distinguishing mathematical outcomes is an indication that 'being mathematical' is as much about having a certain attitude as it is about the possession of a discernible set of skills and procedural facts. To gauge a student's mathematical achievement it might be necessary to actively watch the student as an activity is undertaken. The outcome of the activity, if it is said to be an artefact, might not reveal the processes that went into its construction. An apparently mathematical feature might, for example, have arisen by chance or through a trial-and-error process of experimentation. This illustrates the practical difficulty of discerning mathematical outcomes from artefacts that incorporate a variety of procedural elements—STEM activities, to be sure.

One resolution is to fracture the integrated character of a STEM task into separate components: a mathematical component would be taught and assessed using modes familiar to the mathematics teacher. The art of abstraction is fundamental to mathematical behaviour, after all, and so it might not surprise that this could hold appeal for teachers of mathematics.

And yet, it does seem to run counter to any effort made to generate an integrated STEM task: is there not a synergy to be experienced when one behaves mathematically in a scientific or engineering context? When one thinks mathematically and uses or creates technology to enable the production of an artefact, the mathematical effort might be shrouded and yet none the less integral for that. Does fracturing STEM risk collapsing synergy?

This, however, speaks primarily of mathematics-in-use. What of mathematical instruction in ideas abstracted from application? How is a teacher to engage students with new mathematical ideas, even when it is anticipated that those ideas will have direct relevance to a current STEM activity? Is it better to take students aside and “teach” them the new ideas, or to allow the students to discover a need and seek assistance? Is the difference purely organisational, or is there a pedagogical consideration? How likely is it that students will recognise a mathematical need and seek supplementation whilst engaged in a STEM activity? How, in short, do we best fit students with mathematical techniques and attitudes relevant to STEM activities?

The point in asking questions such as these is not to promote a search for ‘correct’ answers. It is, rather, to promote awareness and to encourage reflection on what we do when—or if—we claim to be promoting STEM. As teachers of mathematics we can celebrate opportunities to articulate our interests and we can challenge our perceptions of what those interests are through careful reasoning.



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